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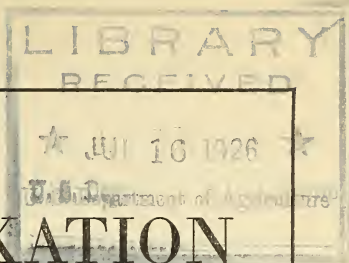
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# NITROGEN FIXATION

## A NEW FORM OF AGRICULTURAL AND MILITARY INSURANCE

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FIXED NITROGEN  
RESEARCH LABORATORY  
U. S. DEPARTMENT OF AGRICULTURE



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## NITROGEN FIXATION

### A NEW FORM OF AGRICULTURAL AND MILITARY INSURANCE

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The statement of Sir William Crookes, in 1898, that the supply of Chilean nitrate would soon be exhausted and that the world would then starve unless some permanent source of nitrogenous fertilizer could be found, had a marked effect in arousing the world to the coming importance of nitrogen fixation. Although at the present time there is no danger that the world will suffer from the immediate exhaustion of the supply of Chilean nitrate, the situation created by the outbreak of the World War when the United States found itself without adequate provision for an emergency supply of fixed nitrogen within its own borders, and incidentally far behind Germany and some other European countries in the development of nitrogen fixation as an element in the national agricultural policy, served again to forcibly emphasize the importance of this art. Under the sudden urge of military necessity, but supported almost equally by that position of the public sentiment resting on the permanent economic issue involved, Congress included in the National defense act of June 3, 1916, the provision:

The President of the United States is hereby authorized to make or cause to be made such investigations as in his judgment are necessary to determine the best, cheapest, and most available means for the production of nitrates and other products for munitions of war and useful in the manufacture of fertilizers and other useful products by water power or any other power.

Thus it will be seen that in somewhat less than 20 years public opinion combined with military necessity had demanded the insurance of an American fixed-nitrogen industry and within less than 30 years this insurance had become an accomplished fact.

### NITROGEN IN AGRICULTURE

The agricultural phase of the nitrogen problem is undoubtedly deserving of most emphasis, because here it reaches its widest human interest. What is done with the nitrogen problem in the next 10 years will probably determine to a considerable degree whether present American standards of living can be maintained. There

seems no escape from the conclusion that unless relatively cheaper fixed nitrogen can be supplied to agriculture steady decrease in crop production will continue, while our population is increasing rapidly. In the past agricultural production has kept pace with the growth of population, not by increasing the yield per acre but by continually increasing the acreage of cultivation, expanding into the richer soils of the Middle West, and abandoning the poor areas of the East. The end of such a program is approaching, not only because nearly all of the easily available areas are under cultivation but also because high labor and material costs and the accompanying high freight rates are already powerful factors acting to reduce the acreage of cultivation. Intensive crop production must ultimately be obtained and one very vital problem in such a program is the procuring of cheap nitrogen. The general feeling of agricultural producers is that they are as yet far below the upper limit of production capacity and need only a market yielding a reasonable return on cost of production, but disregarding temporary situations and looking ahead a few decades, it does not appear that American agriculture will lack a market for the utmost it can produce.

## FERTILIZERS IN AGRICULTURE

In considering the part which nitrogen plays in agriculture, it is well to examine the economic changes which are taking place in the fertilizer industry, and indicate briefly what influence the developing nitrogen industry will have in the future.

Commercial fertilizers are materials carrying nitrogen, phosphorus, or potassium in forms available as plant food. Mixed fertilizers are mixtures of two or more of such materials, and the chemical analysis of the mixture is usually expressed in terms proportional to the percentage of each plant food present; thus the common 2-8-2 mixed fertilizer contains the equivalents of 2 per cent of ammonia ( $\text{NH}_3$ ); 8 per cent of phosphorus anhydride ( $\text{P}_2\text{O}_5$ ) and 2 per cent of potassium oxide ( $\text{K}_2\text{O}$ ).

The phosphorus for fertilizer is obtained from the phosphate rock beds of Florida, Tennessee, and Idaho. In order to render the phosphorus available as a plant food, the rock must be treated with about its own weight of strong sulphuric acid. The rock originally contains the equivalent of about 32 per cent of phosphoric anhydride ( $\text{P}_2\text{O}_5$ ). Adding the sulphuric acid, which reacts with the phosphate rock to form a solid mass, gives a material containing the equivalent of 16 per cent phosphoric anhydride ( $\text{P}_2\text{O}_5$ ), and it is this material, suitably prepared for use, which comes on the market as acid phosphate fertilizer. This constitutes by far the greatest tonnage of any single material handled by the fertilizer industry, and



this fact must be recognized in considering any program for obtaining cheaper mixed fertilizer.

The potassium compounds for mixed fertilizer are obtained almost entirely from the German and Alsatian potash mines, production in the United States amounting to only a small percentage of the consumption.

The nitrogenous materials for mixed fertilizer are assembled from a variety of sources. The meat-packing industry at one time organized fertilizer companies as a means of disposing of nitrogenous waste materials (tankage, blood, etc.). The bulk of these materials now find use as stock feed, only such as are unfit for this use being worked up as fertilizer. Cottonseed meal is also used as a source of nitrogen, and the fertilizer interests own many of the cotton-oil plants. Here again, however, cottonseed meal is finding a better market as stock feed, and the tendency is to throw into fertilizer only a poor grade meal. The same is true of the fish scrap, which formerly went into mixed fertilizer, but now finds another market as hog and poultry feed, only such part going into fertilizer as can not be placed in the higher-priced market, or such as must be acidulated at the factories. All these materials, tankage, cottonseed meal, and fish scrap are, when properly manufactured, high-grade stock feeds, while at best they are but low-grade fertilizer, their chief value lying in the fact that they serve to "condition" a mixed fertilizer; that is, keep it dry and of the right consistency to use at the farm. Aside from these so-called "organic ammoniates," the fertilizer industry serves as a scavenger for a wide variety of similar animal and vegetable nitrogenous waste materials. There is a growing tendency to replace these low-grade nitrogen carriers with so-called "inorganic nitrogen," particularly in the form of ammonium sulphate and Chilean nitrate.

It is important to point out that with the exception of the Chilean nitrate and the small quantity of synthetic nitrogen compound (cyanamid) all the nitrogen in fertilizers in this country is of by-product origin. This fact automatically limits the production of these by-product nitrogen compounds to the ability of the respective industries to dispose of their main products. Further, since the profits derived from by-products serve primarily to enable any industry better to meet competition on its main product, it is evident that nitrogenous by-products will be sold at the best market prices fixed by those nitrogen compounds which are derived as the primary products of an industry. It is for this reason that Chilean nitrate fixed the general price level in the United States for nitrogen compounds in the fertilizer industry, and will continue to do so until an air-nitrogen industry is developed which will seek to market its main product in direct competition with Chilean nitrate.

Much prominence has been given the fact that mixed fertilizers taken as a whole, contain but little plant food, and a great deal of inert material. The cost of handling this inert material, and particularly the freight charges which accumulate against it, are, of course, reflected in the final high cost of the plant food bought by the farmer. Blame for this state of affairs is often laid at the door of the fertilizer industry. Although it is true that in order to meet specific formulas, the mixed fertilizer manufacturer must in some cases add a certain quantity of inert "filler," this amount is small compared with the inert material which results from starting out with such low-grade fertilizer materials as are now available. There is no remedy so long as mixed fertilizers are made up by compounding materials containing at the outset only a low percentage of plant food. This is another argument for using less of the "organic ammoniates" which are all very low in nitrogen. Indeed, since the producers of animal tankage and cottonseed meal are less interested in disposing of these products as fertilizer, the fertilizer industry is itself carrying on an intensive campaign for use of so-called "high analysis" fertilizers. Commendable as this effort is, it must be recognized that what is now called "high analysis" fertilizer still contains less than 16 per cent of the three elements of plant food, and that the excessive freight item now included in the cost of fertilizer at the farm can never be cut out by such feeble reforms. The problems will be solved only when there is available for mixing in fertilizers raw materials rich in plant food at prices which will permit their use. This applies to both nitrogen and phosphorus-bearing materials.

It has been pointed out that the manufacture and sale of acid phosphate constitutes the main activity of the fertilizer industry, and that any program for getting cheap mixed fertilizer must take into account both the nitrogen and the phosphorous phases of the situation. The reason for the preponderance of acid phosphate in the fertilizer business to-day is the very simple one that it pays the farmer to use acid phosphate wherever it is the limiting factor in any crop production, while the use of nitrogenous fertilizer is not always justified at present prices of nitrogenous fertilizer. As an illustration of the situation, let us consider the value of phosphorus and the nitrogen removed from the land by a heavy crop of corn, say 100 bushels per acre. The phosphorus in the grain and fodder of 100 bushels of corn is about 23 pounds; the nitrogen is 148 pounds. At a price of \$16 per ton of acid phosphate delivered at the farm, it would cost only \$2.62 to replace the phosphorus; the nitrogen, however, would cost \$28.42 if replaced with Chilean nitrate at \$60 per ton.

Another illustration will make clear the situation with reference to nitrogen. Let us assume that a very moderate application of nitrogen will increase crop production 10 per cent. Apply this to a cotton crop of 750 pounds of seed cotton per acre and the increase at 20 cents per pound of cotton is worth \$15; applied to a wheat field yielding 20 bushels per acre, the increase yield, at \$1 per bushel, is worth \$2.

If nitrogen could be obtained cheap enough there appears no reason to doubt that the crop production per acre could be greatly increased without a large increase in labor cost. Under present practices of fertilizer application, it is probable that more phosphorus is being returned to the soil than is being removed. It is certain, on the other hand, that the soils of the United States are steadily growing leaner in nitrogen content.

Considered broadly, there are three developments necessary before cheap fertilizer can be made available to the farmer. First is the perfection and expansion of the air-nitrogen industry to a point where it can produce sufficiently cheap nitrogen; second, production of cheap phosphoric acid, or its equivalent to replace the present low-grade (16 per cent) of acid phosphate; and third, elimination of all low-grade plant food materials from the fertilizer industry in order to cut out the present excessive freight and handling costs. These changes involve, on the one hand, rather radical departures from present practices, and, on the other, education of the farmer to use high-grade materials effectively. For both these reasons, the changes will come gradually as the result of numerous developments and economic adjustments.

## MILITARY REQUIREMENTS OF FIXED NITROGEN

Since smokeless powder and high explosives contain fixed nitrogen as an essential ingredient, modern warfare can not be carried on without an abundant and assured supply of fixed nitrogen. The World War brought home to all the belligerent nations the danger of relying on the Chilean nitrate supply for a material so intimately related to national security, and the remarkable achievement of Germany in arriving at independence of the Chilean supply through intensive development of her air-nitrogen industry during the war, brought nearer the day when the world can consider the nitrogen problem as solved.

Until a large air-nitrogen industry has been firmly established in this country as a peace-time project, the matter of an adequate supply of fixed nitrogen for war-time demands will require most careful consideration, but it will be shown in the following that the United States could to-day enter a war calling for a tremendous military effort without regard for continued access to the Chilean supply of



nitrate. This fortunate situation is the direct result of our activity in building nitrogen-fixed plants, during the World War, particularly the big cyanamid plant at Muscle Shoals.

It must be recognized that in any attempt to forecast the military demands for fixed nitrogen in war time, numerous assumptions must be made, and that the estimate can be only approximate. It is possible, however, to make a rough estimate, using the World War data on nitrogen consumption and our experience in mobilizing fighting units.

Assuming that the United States became involved in a war which would ultimately require a very great military effort, involving the eventual mobilization of say 3,500,000 men, military experts have estimated that the fixed nitrogen requirement to maintain the combat units of such a military organization would require in the neighborhood of 12,000 tons of fixed nitrogen per month. The manufacture of this quantity of fixed nitrogen would require somewhat less than four plants the size of No. 2 at Muscle Shoals, unless some of the by-product nitrogen were to be diverted temporarily from agricultural to military uses, in which event fewer plants would be required. Such a diversion would be permissible, however, only for a short time, since owing to the shortage of manpower on the farms, during such an emergency, nitrogenous fertilizer is more necessary than ever.

### NITROGEN FIXATION PROCESSES

In tracing the developments in nitrogen fixation, it will be of interest to compare the power requirements of the various fixation processes together with the nitrogen produced by that process since 1915, as shown in Table 1.

TABLE 1.—*Power requirements of various fixation processes and nitrogen produced in stated years*

Process	Kilowatt-hour per metric ton nitrogen	Percentage of total fixed nitrogen produced				
		1915	1917	1920	1923	<sup>1</sup> 1926
Arc.....	68,000	14.3	10.4	7.7	8.3	5.8
Cyanamid.....	15,000	61.6	50.3	50.7	36.5	27.1
Direct synthetic ammonia:						
a. Electrolytic hydrogen.....	20,000				2.5	4.6
b. Water-gas hydrogen.....	4,000	24.1	39.3	41.6	52.7	62.5
Total production (metric tons).....		99,700	267,270	320,770	511,620	650,900

<sup>1</sup> Estimated.

The table shows in general that production by processes having high energy requirements is gradually decreasing in favor of the lower energy requirements of the direct synthetic ammonia process.

The arc process requires the largest quantity of electrical energy per ton of nitrogen fixed and, consequently, has found a foothold

only in those countries having large amounts of water power available at a sufficiently low price; in other words, in countries where the industrial demands for power are small. With the exception of small unimportant plants in Austria, France, and the United States, Norway is the only country having extensive arc-fixation plants.

The arc process, yielding nitrate nitrogen directly, requires a large and expensive system of absorption towers to remove a dilute nitric acid which may then be utilized in the production of nitrates.

The usual product of the Norwegian arc plants is calcium nitrate (Norwegian saltpeter) containing approximately 13 per cent of nitrogen. It is marketed widely throughout Europe where it comes into direct competition with Chilean nitrate for fertilizer purposes. In addition to calcium nitrate, some sodium nitrite and nitrate are also produced which are exported for use in the chemical industry.

The cyanamide process, using less than one-quarter of the electrical energy of the arc process, has as its main product calcium cyanamide, a compound which has found some application directly as a fertilizer. In this connection, it is not altogether satisfactory; it is necessary that it be used with some care and only on certain soils and further, it is a disagreeable material to handle. In the manufacture of mixed fertilizer, it has been found valuable as a conditioner. For these reasons, the agricultural consumption of cyanamide is limited; however, it has other extensive uses in the chemical industry. The process dates back to the discovery, patented in 1895-1898 by Frank and Caro, that heated calcium carbide reacts with nitrogen to form calcium cyanamide. The commercial substance usually contains from 18 to 22 per cent of nitrogen, together with some lime and graphite. Its objectionable dustiness is somewhat improved by hydrating the free lime and treating with a small quantity of oil.

The nitrogen in calcium cyanamide may be easily obtained as ammonia by treating with boiling water under pressure. It is then available for the production of various ammonium salts or it may be oxidized to nitric acid.

The direct synthetic ammonia process, the newest of the three, had its beginning in the work of Prof. F. Haber, who, in 1905-6, first outlined the general conditions for a successful solution of the problem. The process first found commercial application in 1913, when some 7,000 tons of nitrogen were fixed in this way at the Oppau factory in Germany. This factory was rapidly enlarged during the war, eventually attaining a production of 100,000 tons per year. Further expansion occurred during this period when a much larger factory was built at Merseburg, which will eventually have a capacity of 300,000 tons per year.



Largely because of the low power consumption, and in spite of the technical difficulties involved, the synthetic-ammonia process has outdistanced in rapidity of development all of the other fixation processes, and in the immediate future at least, will continue to do so.

The synthesis of ammonia is accomplished by passing a compressed mixture of purified hydrogen and nitrogen over a catalyst maintained at a relatively high temperature (450 to 600° C.). In this temperature range, within which present catalysts are active, the chemical equilibrium between hydrogen, nitrogen, and ammonia does not permit the formation of technically important concentrations of ammonia except at high pressures (100 to 1,000 atmospheres). Even at the highest pressures now employed, it is not possible to effect the complete conversion of hydrogen and nitrogen to ammonia in a single pass over the catalyst, and it is necessary, therefore, to submit the unconverted gases to the action of the catalyst again after the ammonia formed by the preceding pass over the catalyst has been removed. The method for accomplishing this constitutes one of the chief points of difference between the various synthetic-ammonia processes. On this basis, there are two types of operation, usually referred to as the cyclical and the series processes.

In cyclical operation, the gas is circulated successively through a catalyst chamber and an ammonia condenser or scrubber, the pressure being maintained by the admission of hydrogen and nitrogen in sufficient quantities to replace that removed as ammonia. In series operation, the gas is passed once through a series of units, each of which comprises a catalyst chamber, and an ammonia condenser. The only series process is that of Claude which operates at 900 atmospheres. The other processes, including the original Haber process, on which they are based, are all of the cyclical type and operate at pressures from 100 to 600 atmospheres.

The synthetic-ammonia industry began with the discovering of a suitable catalyst, and the direction of the development of the process has since been determined by the properties of the catalyst. The development of a catalyst capable of synthesizing ammonia rapidly at lower temperatures would permit the use of much lower pressures than are now employed and might alter radically the present type of process. All of the catalysts now in commercial use have iron as the basic constituent, but differ from one another in respect to the foreign materials or promoters which are incorporated with iron. The catalyst developed at the Fixed Nitrogen Research Laboratory is obtained by the reduction of an intimate mixture of iron oxide with about 3 per cent of alumina and 1 per cent of potassium oxide. The performance of catalysts varies markedly with the purity of the

hydrogen-nitrogen gas mixture on which it operates, and the problem of gas production and purification is now one of great importance.

## PRODUCTION OF HYDROGEN

The most important source of hydrogen for the synthetic-ammonia process is water, from which it may be obtained by electrolytic decomposition or by chemical reduction with suitable substances, as for example, by carbon in the manufacture of water gas. Another, but more limited source is coke-oven gas, from which hydrogen can be separated by liquefaction and distillation. The three methods of hydrogen production, known as electrolytic, water-gas, and coke-oven gas, now supply all of the hydrogen used for ammonia synthesis. At the present time the largest production of ammonia is from water-gas hydrogen, the great German plants at Oppau and Merseburg producing annually about 350,000 tons of fixed nitrogen as ammonia by this process. The catalytic water-gas process yields a valuable by-product, carbon dioxide, which finds application in the production of urea and ammonia sulphate by the gypsum process.

## CONVERSION OF AMMONIA TO OTHER NITROGEN COMPOUNDS

Of importance second only to the fixation of nitrogen is the conversion of the initial products of fixation to products best adapted to meet the various requirements of agriculture and the chemical and explosive industries. Most of these compounds are readily derived from ammonia as a starting point.

Ammonium salts, such as the sulphate, phosphate, nitrate, and chloride can be produced by neutralization of ammonia with the appropriate acid. Ammonium chloride may also be produced as in the Solvay process and ammonium sulphate is at present being made in Germany by the interaction of gypsum, water, ammonia, and carbon dioxide. The largest use for ammonium salts is in fertilizers.

Urea, a most desirable fertilizer salt, may be produced by direct interaction of ammonia and carbon dioxide. Small quantities of urea have been made in Germany, and the process is almost certain to find wide application particularly in conjunction with synthetic-ammonia plants producing hydrogen by the catalytic water-gas process, since large quantities of carbon dioxide are then available.

One of the most important transformations of nitrogen compounds is that from ammonia to nitric acid. It is the link between ammonia and nitrate nitrogen. Nitrogen in the form of nitrates is required in the explosives and chemical industries as well as in

fertilizers. The oxidation of ammonia is accomplished by passing a mixture of ammonia and air over a heated catalyst, usually a platinum gauze. The oxides of nitrogen thus formed may be absorbed in water to yield nitric acid or in alkaline solution to produce nitrates.

## DEVELOPMENTS IN NITROGEN FIXATION IN THE UNITED STATES

### HISTORICAL

The earliest attempt to establish an air-nitrogen industry in the United States was that of the Atmospheric Products Co. in 1902, at Niagara Falls, N. Y. The scheme involved use of electric arcs in a furnace invented by Bradley and Lovejoy. For various reasons the project was a failure, but it is of historical interest as antedating shortly the successful installations of the arc process in Norway in 1903.

The next attempt to establish a nitrogen-fixing plant appears to have been that made at Nitrolee, S. C., in 1908. This was also an arc plant, producing nitric acid. Later, equipment was added for converting the nitric acid to calcium nitrate fertilizer. In 1913 the project was temporarily abandoned; but, when the war in Europe caused a considerable advance in the price of nitric acid, another effort was made to operate the plant profitably. In 1915 a little ammonium nitrate was made, but soon after this the plant was closed and has not been operated since.

Meanwhile, in 1910, the American Cyanamid Co., of New York, put a small cyanamid plant into operation on the Canadian side of Niagara Falls. The capacity of this plant was increased from its initial one of about 3,500 tons of fixed nitrogen per year, to 7,000 tons in 1911, and to 13,000 tons in 1916. Although this plant is not properly included among American plants, being located on the Canadian side of the falls, the practical result is the same in most ways, for nearly the whole output of the plant is brought into the United States.

In 1917, the American Nitrogen Products Co. put into operation a small arc plant at La Grande, Wash., and this was the one and only nitrogen-fixing plant in operation in the United States in the year this country entered the World War. The capacity of the La Grande plant is about 350 tons of fixed nitrogen per year, or the equivalent of about 2,250 tons of Chilean nitrate. During the year 1918 the United States imported 2,066,483 tons of Chilean nitrate, or nearly a thousand times as much nitrogen as our total nitrate nitrogen production capacity at that time. We had, of course, our domestic by-product ammonia available, and if necessary a considerable quantity



of it could have been converted to nitric acid. If, however, every pound of by-product ammonia produced in the United States in 1918 could have been gathered up and oxidized to nitrate nitrogen, the total would have been the equivalent of about 490,000 tons of Chilean nitrate, or less than one-quarter of our imports for the year.

During 1917, various agents of the Government studied the nitrogen situation and committee reports were submitted. Meanwhile the United States had been drawn into the World War, the need for safeguarding the nitrogen supply of the country was much more urgent. Finally, the President approved a program calling for the construction of a nitrogen-fixing plant using the General Chemical Co.'s process, the construction of an ammonia oxidation plant and an experimental program with regard to the Bucher cyanide process and other nitrogen-fixing schemes. United States nitrate plant No. 1 at Sheffield, Ala., and eventually the cyanide plant at Saltville, Va., were built in following out the above program and there was also undertaken numerous research projects. Later on the Government built nitrate plant No. 2 at Muscle Shoals, using the cyanamid process, and began the construction of plants No. 3 and No. 4 in Ohio.

All of this construction was pushed vigorously, but the war ended before any of the plants were ready for production. In plant No. 1 one unit was ready for production, but operating difficulties were encountered and there was very little ammonia produced. Plant No. 2 was nearing completion and a few months after the armistice was given a test run and found to be satisfactory. Construction of plants Nos. 3 and 4 was well under way at the date of the armistice, but work on these was halted at once, and later the materials were scrapped.

As a net result of its activities, the Government had at the end of the war an unsuccessful ammonia plant at Sheffield, Ala., and a successful cyanamid plant at Muscle Shoals having an annual capacity of 40,000 tons of fixed nitrogen. There had also been accumulated a considerable volume of experimental data at the various research laboratories which had been established. Shortly after the war, both plant No. 1 and plant No. 2 were put in stand-by condition and have not been operated since. The research on nitrogen fixation which had been carried on at various laboratories during the war was finally consolidated at the Fixed Nitrogen Research Laboratory, Washington, D. C., where the work is still prosecuted vigorously.

The commercial development of nitrogen fixation in this country, although beginning rather recently, is well under way, and it is expected that this year it will reach a production of close to 100 tons of ammonia per day.

## FIXATION OF NITROGEN BY SOIL BACTERIA

Of the nitrogen-fixing bacteria which live in the soil, those which are symbiotic with leguminous plants are of most importance to agriculture, for in regions where soil conditions, rainfall, etc., permit the growing of legumes, these crops provide a method of returning to the soil a part of the nitrogen removed by other crops. In some localities, possibly all of the nitrogen required may be met by use of such crops, particularly where they can be grown as catch or cover crops between the regular annual crops. It does not appear, however, that the growing of legumes can be considered as a general solution for the problem of nitrogen supply in American agriculture. Where legumes are raised in a regular rotation of crops on a three or four-year schedule, if it is not profitable to plow under the whole crop. Since a legume crop is harvested as livestock feed it is evident that only by a very large increase in our livestock production could the legume crop be utilized, should one-quarter of the total cultivated area of the country be in legumes annually. An urge for increased food production, however, inevitably drives agriculture toward direct human food crops and away from livestock production. Further, there are many sections of the country where rainfall is the limiting factor in crop production, and since some legumes have a very large moisture requirement, they can not be grown in such sections. This condition obtains over much of the wheat-growing areas of the United States. A further deterrent to the wider use of legumes is the fact that legumes require a soil free from acidity and in order to raise legumes on many of our soils, it would be necessary to make a heavy preliminary application of lime. This expense and the subsequent one of raising a low-value legume crop may render this method of adding nitrogen to the soil unprofitable.

The 1920 census revealed about 57,000,000 acres in legumes out of our total of 503,000,000 acres of improved land. Considering the various factors involved, it does not appear likely that any very considerable increase in acres of legumes may be expected. Although fullest advantage must be taken of legumes where possible, it is well to recognize the natural limits of this means of obtaining fixed nitrogen, and particularly it is important that in every specific case the cost of nitrogen by this means be balanced against the cost of the same quantity of nitrogen from commercial fertilizer.

## FUTURE DEVELOPMENTS

Although somewhat over 20 years has been devoted to a consideration of the nitrogen problem, a satisfactory solution is as yet lacking. It is true we can now fix nitrogen as ammonia at a price lower than



that of the present price of the natural nitrates; however, the conversion costs of ammonia to the desired nitrate form is higher than desirable and synthetic nitrates in this country at least cost more than the farmer can afford to pay.

The problem is essentially a chemical one and can only be solved by intensive research of a fundamental nature, since the solution will undoubtedly be formal in hitherto unexplored fields. Such research, being of a pioneer nature, can most satisfactorily be carried out in Government or university laboratories, since there an environment conducive to scientific experimentation of the most detached type can be fostered untroubled by insistent commercial demands for immediate financial returns. Furthermore, the final solution of the nitrogen problem must be approached not only with a view to supplying the possible demand for fixed nitrogen, however large that may be, but a satisfactory solution will also depend upon an economic consideration of the natural resources of this country with an adjustment of these resources to those industries which can best make use of them, not for the sake of immediate private gain, but for the best interests of the whole population. Such an adjustment has to some extent already taken place, in the gradual development of the fixation industry away from a large consumption of electrical power to one in which cheaper sources of energy are used.

### THE FIXED NITROGEN RESEARCH LABORATORY

The necessity for research in the field of nitrogen fixation has been appreciated by the Government for a number of years. Experimental work on the fixation of nitrogen by the arc process and the synthetic ammonia process was started as early as 1915 by the Bureau of Soils of the Department of Agriculture. During the war research on nitrogen fixation was carried out in a variety of fields by the technical research branch of the Ordnance Department, in the Bureau of Soils, the Geophysical Laboratory, and the Bureau of Mines, the Bureau of Standards, and a number of other agencies. At the close of the war the Fixed Nitrogen Research Laboratory was created by an order of the Secretary of War on March 29, 1919, which took over the work of the various agencies.

During the six years of the existence of the laboratory, the work has been directed among all the ramifications of the nitrogen problem. Most of the important developments have been published from time to time by the staff of the laboratory in the various scientific and technical journals. The experience gained in these years, together with the large amount of information obtained by keeping in close touch with the nitrogen situation throughout the world, has made it of immense value to the Government and industry in general.



Gen research lab.  
1926.

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